RBMK-1500 reactor void reactivity factor measurements at a low power level

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INTRODUCTION

The measurements of physical and dynamic characteristics of INPP unit 1 reactor were carried out on May 2, 2000. These measurements were carried out before the reactor shut down for the planned preventive outage. Void reactivity factor α_φ, fast power reactivity factor α_w and first azimuth power distribution harmonics period τ_{01} has been measured.
These measurements were carried out according to the established plant procedure.
During the measurements the following means of registration of technological parameters were used:
- Nuclear Safety Department recorders (reactor power by in-core detectors and side ionization chambers, reactivity, feed water flow-rate, feed water from emergency feed water pumps (EFWP) and steam flow-rates, pressure and levels in drum-separators (DS) etc.);
- Information and computing system (ICS) registration of in-core detectors readings, control and protection system (CPS) rods positions;
- Visual registration of the CPS rods positions.

The works were carried out under the supervision of the technical director deputy on operation at the presence of the VATESI (Lithuanian regulatory authority) inspector; the technical supervision was carried out by the Nuclear Safety department head.

REACTOR INITIAL STATE

The reactor initial state on 2000-05-02 before measurements is presented in the Table 1.

THE TABLE 1

№	Parameter	Value
1.	Reactor thermal power, MW	1960
2.	Reactor burn-up, eff.days	2919
3.	Reactor loading: Fuel Assemblies (FA with Er)	1646 (983)
	Additional Absorbers	9
	Non-loaded Channels	6
	Assembly 83	0
	Absorber Pins	1
	Control Rods 2477-type	96
4.	Average FA burn-up, MW·days/FA	1107
5.	Operational reactivity margin, MCR rods	56.2
6.	Radial power distribution peak-factor	1.37
7.	Average axial power distribution peak-factor (by 12 APDS)	1.20
8.	Average relative 2 harmonics value of axial neutron flux distribution (by 12 APDS)	-0.066
9.	Average calculated graphite temperature, ^{0}C	401
10.	Average AA burn-up, eff.days.	362
11.	Average AP burn-up, eff.days.	119

THE WORKS PERFORMING APPROACH

τ_{01} measurement

The measurement of τ_{01} began on 2000-05-02 at 08.37 and consisted in the termination of influencing the power distribution field by CPS control rods by the manual control switch. The automatic regulator 2AR was in operation in a total mode. The reactor power within a dead zone of 2AR was supported by the central MCR 24-25. The power distribution distortion was monitored by SIC disbalances and RPDS readings on color display, and also was registered by ICS by a special code.
The power distribution has being distorted with the increase of power in upper and reduction in the lower part of reactor loading map.
The τ_{01} measurement took 1 h 58 minutes and was stopped at 10.35 by the Nuclear Safety department head order when a deviation of some RPDS signals from an initial state reached 6-7 %.

α_φ measurement

The measurement of α_φ was executed on 2000-05-02 from 11.16 till 11.52 and consisted in reactor reactivity change measuring after entering the feed water flow rate disturbance (ΔG_{fw}). The reactivity change was estimated on 2AR control rods positions changes and change of reactor power.
3 cycles of feed water flow rate disturbance (±200 ton/h on every side) were carried out. Feed water flow rate and 2AR control rods positions changes are given in the Table 2.

TABLE 2

cycle №	ΔG_{fw} from EFWP left/right, t/h	2AR rods positions, m					α_φ, $\beta_{эф}$
		16-33	32-33	16-17	32-17	Average value	
1	initial	3.00	3.00	2.85	3.00	2.96	
	+ 197/182	2.80	2.60	2.60	2.76	2.69	1.23
	- 197/182	3.00	3.00	2.95	3.05	3.00	1.44
2	initial	3.00	3.00	3.00	3.00	3.00	
	+ 207181	2.75	2.70	2.76	2.71	2.73	1.17
	- 207/181	3.00	3.00	3.10	3.00	3.03	1.32
3	initial.	3.00	3.00	3.00	3.00	3.00	
	+ 206/181	2.90	2.60	2.55	2.70	2.69	1.40
	- 206/181	3.05	2.95	2.85	3.00	2.96	1.21

α_w measurement

The measurement of α_w was executed on 2000-05-02 at 12.00 by 2AR control rods insertion into the core by manual key from position of 3.50 m till 4.00 m. Thus the reactor power (measured by SIC) during the insertion of rods (~2.5 sec) has decreased from 1949 to 1880 MW and in ~30 sec stabilized at a level of 1824 MW.

RESULTS of MEASUREMENTS

The calculation of τ_{01} was carried out by approximation of the registered deviations of RPDS-1 readings by the limited set of harmonics using MAINA code and subsequent processing of amplitudes A01sin using EXPA code. The amplitudes A01cos were not processed, as their change was insignificant.
By the amplitudes A01sin the value of 38.2 minutes is received. The minimal value of τ_{01} is accepted to be equal to 38 minutes. The received value is within the passport range.

Fast power reactivity factor is determined under the formula:

$$\alpha_W = -\frac{\rho_B}{\Delta W_1},$$

where

$$\rho_B = \rho_B^{'} \left(\frac{1}{1 - \frac{\Delta W_T \cdot \Psi}{\Delta W_1}} \right) = -0.027 \left(\frac{1}{1 - \frac{69 \cdot 0.097}{125}} \right) = -0.0285\ \beta_{эф}\ -$$

the real worth of inserted part of 2AR control rods;
ΔW_1 – the final value of neutron power deviation from initial value, MW;
$\rho_B^{'}$ - 2AR control rods worth, measured by reactivity-meter, βef;
ΔW_T – neutron power change during the rods insertion, T≈2.5 sec;

As a result of the executed calculations the value of fast power reactivity factor was equal to -2.3×10-4 βef/MW. The error of α_w measurement is equal to 0.2×10-4 βef/MW. The received value of α_w is within a passport range.

The calculation of void reactivity factor α_φ , measured on 2000-05-02, was carried out at CM-2M computer using TPAKT code. The results of three cycles of feed water flow-rate disturbances of ±200 t/h at the side were processed. Average void reactivity factor is determined from six values of α_φ taking into account their worthies, proportional to total feed water flow-rate disturbance in each cycle. Its value is equal to 1.3 βef . The mean square root error derived from six measurements is equal to 0.1. βef
The α_φ value equal to 1.3 βef does not meet the requirements of the reactor passport and the working program of loading Er-dopped FA into unit 1 reactor up to 1000 pieces.
The results of calculations are given in the Table 2.

Note, that the reactivity decrease due to the unknown reason before entering the disturbance of feed water flow-rate in first two cycles took place. To define the void reactivity factor during measurements by entering the disturbance of feed water flow-rate, all other parameters effecting the reactivity should be supported stable. In first two cycles this requirement is not fulfilled.
Earlier (1999-02-25) at unit 1 the significant deviation of experimental α_φ value from pre-calculated one because of the untightness of gate valve at the water pipeline from EFWP to ECCS occurred. During these measurements the unstabilities of the flow-rate (deviations from 0) measured at control point 1TH10F01 were observed also, that was the evidence of possible undetected leakages. During the nearest outage it is necessary to check this gate valve.

The void reactivity factor value measured on 2000-05-02 at unit 1 should be recognized doubtful, because of :

- After the last measurements of α_φ at unit 1 on 2000-03-15 only Er-dopped FA were loaded into the core; AA were not unloading and non-loaded channels were not loaded;

- Fast power reactivity factor α_w and the first azimuth power distribution harmonics period τ_{01} which are dependent on void reactivity factor value practically have not changed in comparison with the previous measurements and resulted in α_w =-2.3×10-4 βef/MW , τ_{01} =38 minutes on 2000-05-02 (on 2000-03-15: α_w =-2.4×10-4 βef/MW , τ_{01} =35 minutes);

- At unit 2 the measured value was α_φ =0.7 βef with a similar number of Er-dopped FA, AA and non-loaded channels in the loading and larger fuel burn-up on 1998-06-24:

Unit	Date	Reactor power, MW(th)	ORM, MCR	Core loading	FA average burn-up, MW•days/FA	α_φ, β_{ef}
1	2000 05 02	1960	56.2	1646 FA (983 Er FA) + 9 AA + 0 assembly 83 + 6 non-loaded channels	1107	1.3
2	1998 06 24	4100	53.8	1647 FA (950 Er FA) + 9 AA + 1 assembly 83 + 4 non-loaded channels	1124	0.7

- Predicted α_φ value was α_φ =0.7 βef . The preliminary measurements show, that experimental and predicted values coincide satisfactorily (see Table 3);

- Using the database recorded before the measurements the calculated by STEPAN-S code α_φ value was α_φ =0.6 βef ;

- The calculations which have been carried out by RDIPE and Kurchatov Institute using the database recorded before measurements, have given the following results: Kurchatov Institute by STEPAN code has received α_φ =0.81 βef, and RDIPE by SADCO code has received α_φ =0.84 βef and α_w = -2.33×10-4 βef/MW;

TABLE 3

Measured and predicted α_φ values for unit 1 loading Er-dopped fuel

Date	Er FA	AA	Non-loaded channels	W, MW	E, MW•·days/FA	ORM, MCR	α_φ^{meas} β	α_φ^{pred} β	α_w, 10^{-4} β/MW	τ_{01}, min
23.12.96	0	53	1	3400	846	54.4	1.0	0.95	-1.6	20
21.01.97	100	53	1	3700	814	54.7	0.7	0.59	-1.9	27
23.01.97	100	49	5	3470	818	55.9	0.7	0.73	-2.2	31
07.02.97	140	49	1	3550	812	56.7	0.7	0.57	-2.3	25
14.02.97	140	45	5	3520	827	57.6	0.7	0.63	-2.4	25
11.11.97	264	33	5	4100	865	53.9	0.5	0.50	-2.1	24
30.01.98	352	25	5	2320	936	55.5	0.7	0.58	-2.2	25
05.05.98	500	17	1	4020	957	56.0	0.6	0.44	-2.0	38
06.11.98	500	17	5	3200	994	54.6	0.8	0.72	-2.0	22
11.12.98	550	13	5	4020	998	56.3	0.7	0.68	-2.0	20
25.02.99	620	9	5	3060	1054	54.4	1.2*	0.70	-2.1	24
04.03.99	637	9	5	4000	1050	54.2	0.9	-	-1.7	-
17.03.99	663	13	1	2170	1039	54.3	0.6	-	-2.6	26
16.04.99	690	9	5	2200	1051	57.1	0.8	-	-2.3	25
99.05.20	759	9	5	3940	1038	54.9	0.7	0.64	-2.3	27
99.10.20	776	13	1	2250	1046	56.8	0.6	0.78	-2.8	37
00.01.28	900	13	2	3870	1042	54.1	0.5	0.45	-2.2	>20
00.03.15	950	9	6	3150	1074	57.0	0.55	0.54	-2.4	35
00.05.02	983	9	6	1960	1107	56.2	1.3*	≈0.7	-2.3	38

* - doubtful value

The experimental errors are: for α_φ - ±0.2 βef for α_w -±0.2×10-4 βef/MW.

- The present measurements were carried out at the minimal allowed reactor power, that also is the reason of obtaining of doubtful result.

Comparing the plots of reactor parameters change during the worth measuring of 2AR control rods in the present (2000-05-02) and last (2000-03-15) measurements the following could be mentioned. On 2000-03-15 during the worth measuring of 2AR rods the fast enough negative reactivity drop occurred – after the initial input of negative reactivity, equal to -0.024 βef , in 30 seconds negative reactivity was -0.004 βef , in 60 seconds -0.003 βef, and reactor power (by SIC readings) within the interval from 30-th up to 60-th second was stabilized. Otherwise, during the worth measuring on 2000-05-02 after entering the reactivity of -0.027 βef in 30 seconds it resulted in -0.010 βef , in 60 seconds its value was also -0.010 βef, with the subsequent essential enough increase of negative reactivity in 80 seconds up to -0.013 βef , that proves to be true by reactor power behavior without the stabilization. It means that on 2000-05-02 after the initial reactivity input during about 80 seconds there is an negative reactivity input, associated with the change of temperature in suction headers and pressure in DS. Both change of temperature in suction headers, and the change of pressure in DS, result in economizer area increasing, and as a consequence, in the input of negative reactivity due to absorption of neutrons in water. The same phenomenon took place on 2000-03-15 at the higher reactor power, but in this case the economizer area is much less and the entering of negative reactivity has smaller influence because of a smaller neutron flux in this area, than in measurements on 2000-05-02, as the disturbance caused by additional water is square-law dependent on neutron flux. The continuous introduction of negative reactivity during all the measurement means that this process has dynamic nature with positive feedbacks, while the used void reactivity factor calculation method (TRACT code) is based on static model. It proves to be true also comparing the behavior of pressure in deaerator, temperature in MCPs suction headers during the experiments made on 2000-03-15 and 2000-05-02.

CONCLUSION

Void reactivity factor value measured at unit 1 on 2000-05-02 equal to 1.3 β_{ef} is doubtful. After unit 1 reactor start up after planed outage and power stabilization at the operational level it is necessary to repeat the τ_{01}, α_{φ} and α_w measurements at the higher power level (2400 ÷ 4000 MW).